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MANUFACTURING METHODS AND TECHNOLOGY ENGINEERING HIGH EFFICIENC--ETC(U)
JAN 77 H R CHALIFOUR, S R STEELE DAAB07-75-C-0045

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MANUFACTURING METHODS AND TECHNOLOGY ENGINEERING
HIGH EFFICIENCY, HIGH POWER GALLIUM ARSENIDE
READ-TYPE IMPATT DIODES

SIXTH QUARTERLY PROGRESS REPORT

1 OCTOBER 1976 to 31 DECEMBER 1976

CONTRACT NO. DAAB07-75-C-0045

Prepared By

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The X-band and Ku-band confirmatory sample wafers were processed into dice and evaluated. The confirmatory sample diodes were assembled and tested. Group B testing is being performed on the diodes.

Installation and characterization of the thermal resistance testing equipment was completed. The noise measuring equipment was also completed and installed. → next page

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cont

The fifth operating life test was completed for the Ku-band diodes only. Priority for testing of X-band diodes was assigned to the confirmatory samples, delaying start of the fifth X-band life test.

MANUFACTURING METHODS AND TECHNOLOGY ENGINEERING
HIGH EFFICIENCY, HIGH POWER GALLIUM ARSENIDE
READ-TYPE IMPATT DIODES

SIXTH QUARTERLY PROGRESS REPORT

1 October 1976 to 31 December 1976

CONTRACT NO. DAAB07-75-C-0045

The objective of this program is to develop a capability to manufacture High Efficiency, High Power Gallium Arsenide IMPATT Diodes meeting the description and specifications of Section F of the contract and the requirements of SCS-481.

DISTRIBUTION STATEMENT

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Prepared By

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PURPOSE

The objective of this program is to establish a capability to manufacture high-efficiency, high-power Gallium Arsenide IMPATT diodes at specified rates and yields. There are two diode types; one at X-band, and one at Ku-band which have the nominal characteristics listed below:

	X-Band	Ku-Band
Operating Frequency (GHz)	10.0 ±1.0	15.0 ±1.0
Power Output (Watts)	3.5 min.	2.5 min.
Conversion Efficiency (%)	20 min.	20 min.
Operating Junction Temperature	200 max.	200 max.

Engineering effort is to be directed toward establishing production processes for both Gallium Arsenide epitaxial wafers and diode fabrication and test. The wafers are to meet the material characterization testing as specified, and the diodes must meet the detailed performance requirements outlined in SCS-481.

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1.0 INTRODUCTION

From the four wafers of each type grown for this purpose, two X-band wafers and two Ku-band wafers were processed during the period for the purpose of fabricating the confirmatory samples. These wafers were grown in accordance with the wafer specification and meet this specification. The resultant diodes meet the diode specification SCS-481. The diodes are being subjected to the Group B testing.

The thermal resistance testing equipment has been evaluated and approved. The equipment is designed for production testing of IMPATT diodes. The measurement and computation are performed in nine (9) seconds. Including the loading and unloading of the device under test, and data recording, production rates of 60/hour can be achieved, which far exceeds the requirements and is a vast improvement over the prior method. The equipment was designed and built by Sage Enterprises around specifications submitted by Raytheon Company. Circuit modifications were made after the first evaluation to improve accuracy and increase operator control of the test conditions. An accessory digital meter was added for this purpose.

The Ku-band noise measuring equipment, designed and built by an equipment design group of Raytheon's Microwave & Power Tube Division, was completed and delivered to the production line. The instrument met all specifications. The instrument was used for testing of the Ku-band diodes prior to Group B testing and performed well. A direct plot of AM and FM noise is obtained as a function of frequency from the carrier. The use of these instruments will allow us to meet the specified production rates.

The life testing program is continuing. During the period, the fifth Ku-band life test was completed. X-band diodes were not

immediately available and priority was, therefore, assigned to the X-band confirmatory samples which were ready for testing. The fifth X-band life test will be run simultaneously with the Ku-band confirmatory samples.

2.0 RESULTS AND ACCOMPLISHMENTS

2.1 Fabrication of Confirmatory Samples

During the engineering phase of this program, gallium arsenide wafers were grown with the objective of establishing limits on the wafer growth parameters. The approach was to select the best estimate for a particular wafer characteristic and deliberately grow wafers having values at the nominal and others above and below the nominal value. The results of these experiments were reported in previous quarterly reports. As a result of this effort, a wafer specification was drafted for the X and Ku-band wafers. The specification is given in Appendix A. The confirmatory sample wafers were grown in accordance with the wafer specification.

Four (4) X-band and four (4) Ku-band wafers were grown for the purpose of confirming the wafer specification and also for fabricating the confirmatory sample diodes. The characteristics of the eight (8) wafers are given in Table 2-1. It may be seen by comparing the characteristics to the specification that the wafers satisfactorily met the specification.

Two of each of the wafer types were then processed and were evaluated prior to dicing. Evaluation at this stage consists of a complete mapping of the wafer by probing to determine the variation in breakdown voltage, capacitance and V*. Frequency distribution plots of these characteristics are shown in Figures 2-1, 2-2, 2-3, and 2-4. V* is the voltage intercept of the capacitance-voltage curve at the point where the capacitance begins to abruptly decrease. It is the voltage at which the spike is depleted of charge as explained in prior reports on this program.

Subsequent to dicing of the wafers, the confirmatory sample diodes were assembled and fully tested in accordance with the diode specification SCS-481. The test data is given in Tables

Table 2-1

Read Wafers Supplied for Confirmatory Samples

Wafer No.		Buffer	Transit		Spike					Contact		
		W	W	$n \times 10^{16}$	W	$n \times 10^{16}$	$Q^* \times 10^{12}$	V*	x_p	x_o	$n_o \times 10^{16}$	
Series	Run	(μm)	(μm)	(cm^{-3})	(mm)	(cm^{-3})	($c\text{-}cm^{-2}$)	(volts)	(μm)	(μm)	(cm^{-3})	Band
413	19A	4.9	4.6	0.51	50	46.0	2.5	8.9	0.24	0.19	11	X
	19B	5.1	4.7	0.50	50	45.0	2.4	8.1	0.24	0.19	12	X
	20A	5.2	5.1	0.49	52	42.0	2.4	8.6	0.24	0.19	11	X
	20B	5.7	5.4	0.49	52	43.0	2.4	8.1	0.24	0.19	12.5	X
	28A	4.5	3.5	1.03	46	43.7	2.5	8.0	.23	0.19	11	Ku
	28B	4.8	3.7	1.06	46	43.1	2.4	7.9	.23	0.18	11	Ku
	30C	5.6	4.5	1.15	50	42.8	2.4	8.3	.25	0.20	10	Ku
820	10	6.5	4.3	1.10	50	43.0	2.5	8.2	.25	0.20	9.8	Ku

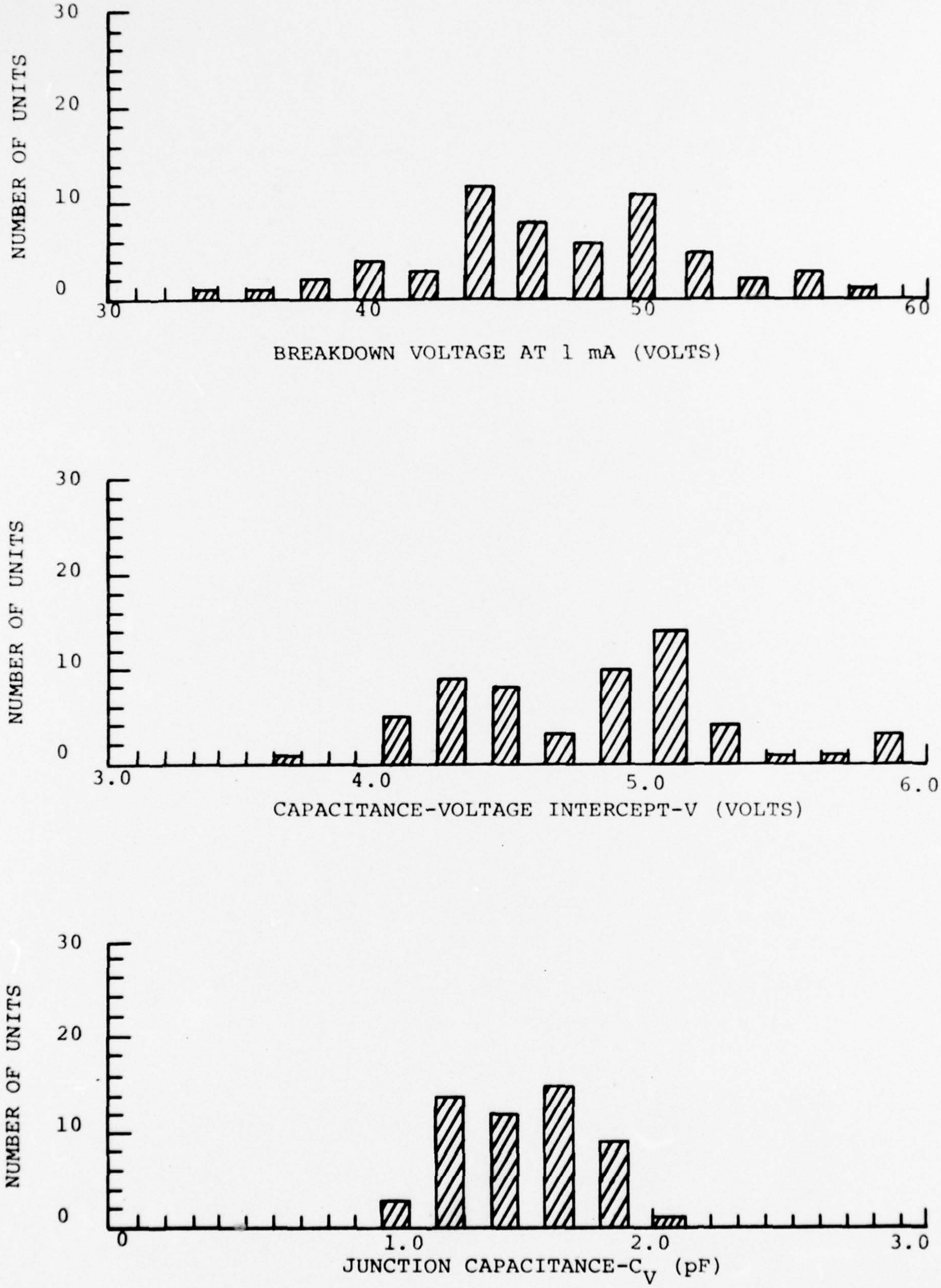

Figure 2-1 Frequency Distribution Plots - Wafer 41319

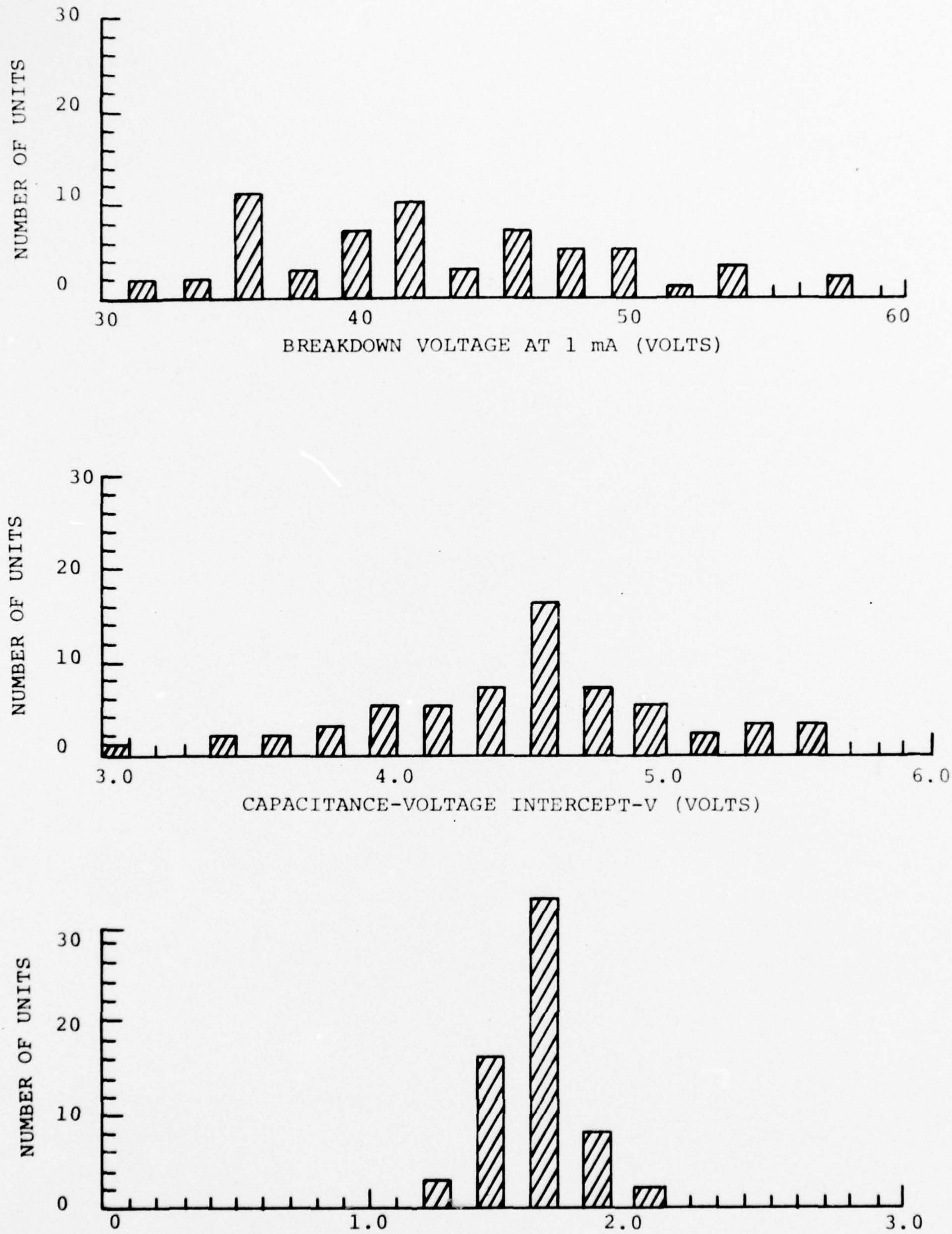

Figure 2-2 Frequency Distribution Plots - Wafer 41320

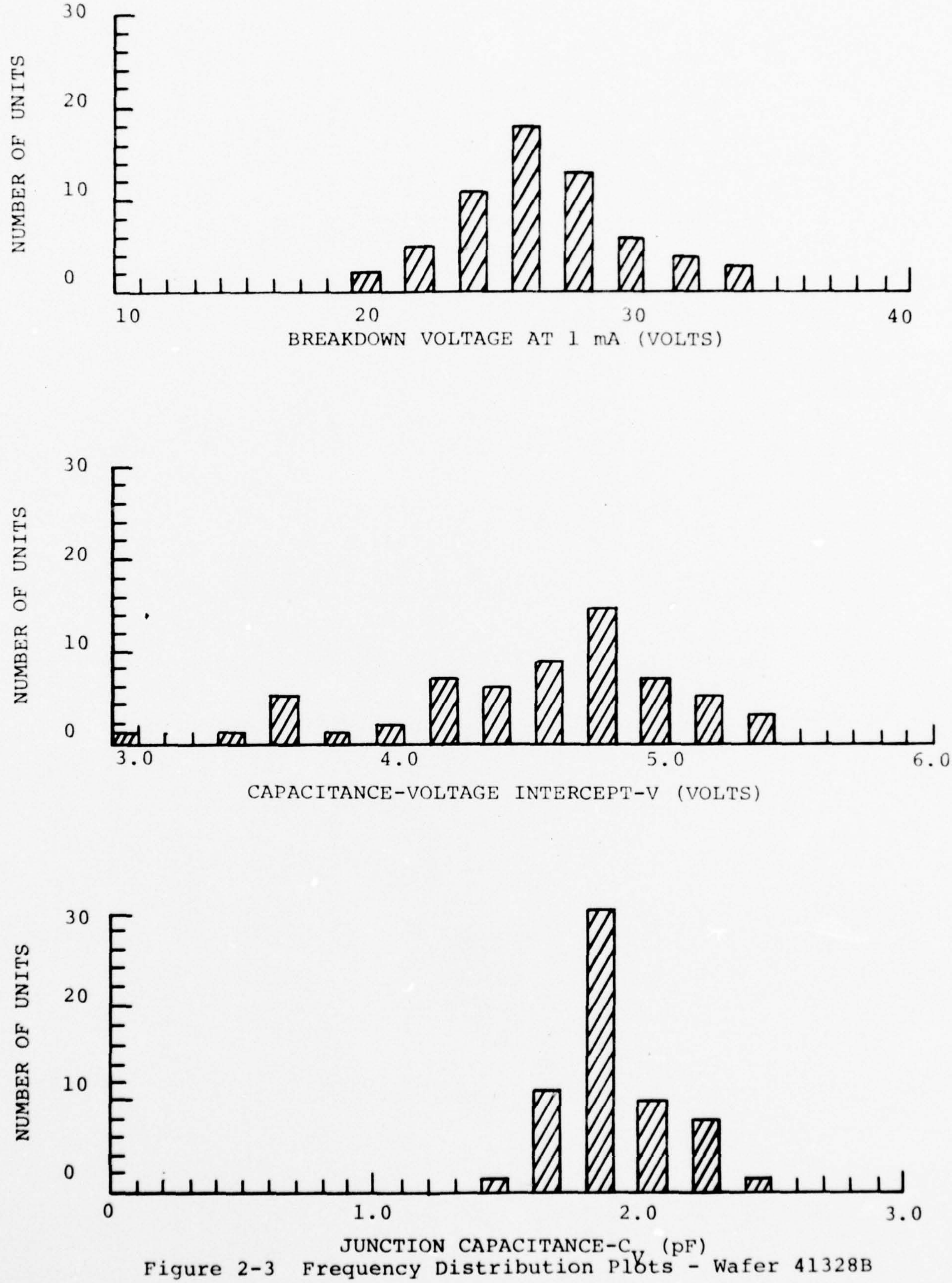

Figure 2-3 Frequency Distribution Plots - Wafer 41328B

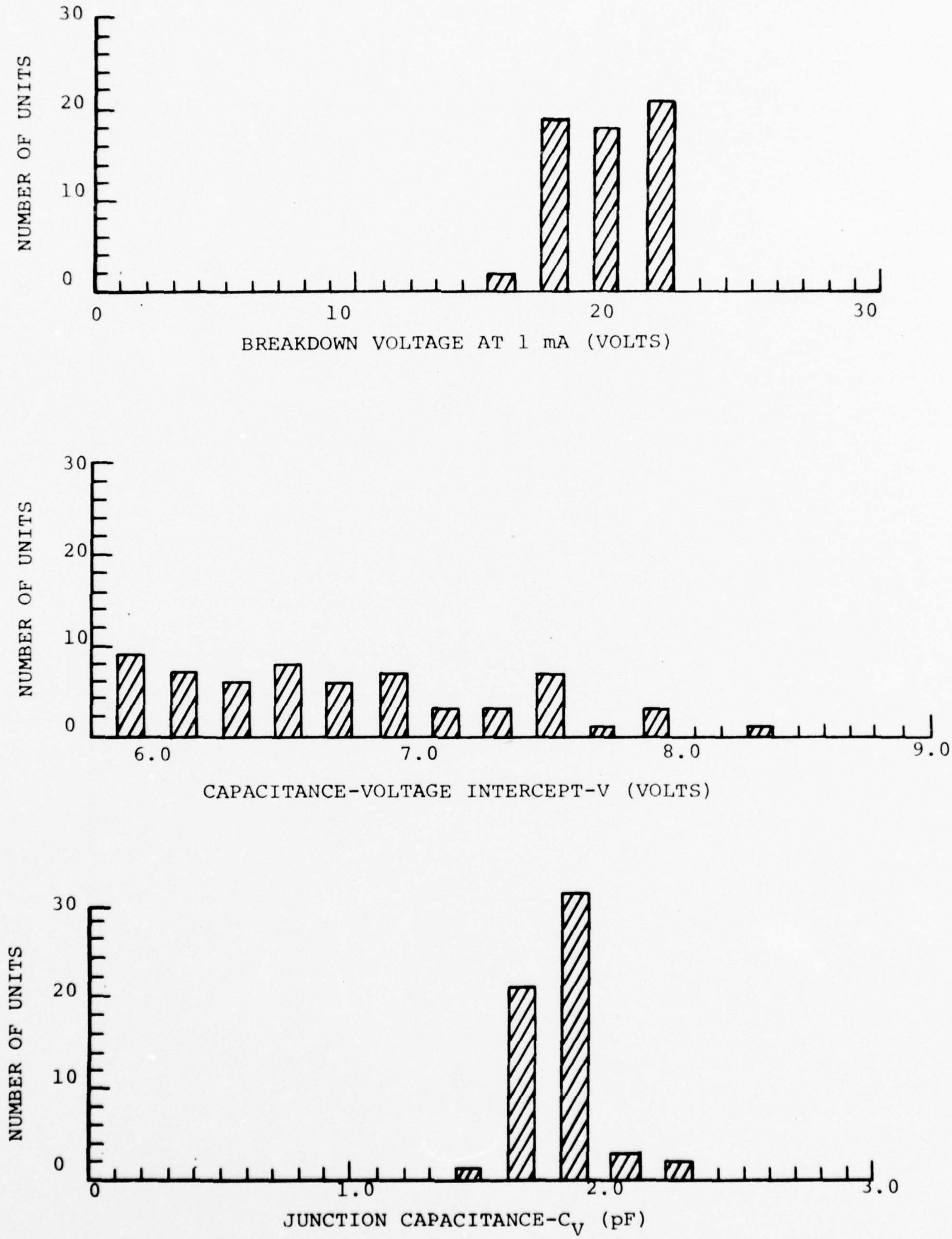

Figure 2-4 Frequency Distribution Plots - Wafer 41330C

2-2 and 2-3 for the X-band and Ku-band diodes, respectively. The specification limits for each of the parameters is also listed in the tables. The deliverable samples (twenty-five of each type) all met the specifications.

Disposition of the confirmatory sample diodes, subsequent to complete Group A testing, is to subject the units to Group B testing as follows:

- 9 diodes of each type to operating life test
- 9 diodes of each type to storage life test
- 3 diodes of each type to nuclear irradiation
- 4 diodes of each type to the sequence
    1) Mechanical Shock - Nonoperating
    2) Vibration - Variable Frequency
    3) Constant Acceleration - Centrifuge
    4) Hermeticity - Fine Leak

The confirmatory sample diodes are presently undergoing the Group B testing.

2.2 Thermal Resistance Testing

The measurement of thermal resistance as performed prior to this program was one of the factors gating the production rate of Read IMPATT diodes. The accurate measurement of thermal resistance is a fairly lengthy two-step process involving first the calibration of the diode breakdown voltage with temperature, and secondly, the use of this calibrated diode thermometer during a pulsed power test to measure the device temperature. Knowing the amount of power dissipated in the device and its temperature, the thermal resistance of the device is calculated. We had been performing this measurement sequence in a multi-station test fixture capable of measuring twelve devices simultaneously. The cycle time was approximately four hours per batch. A doubling of this rate was the minimum required to meet the rate objective of 1000 units/month.

Table 2-2
Data Sheet
SCS-481 Type 1 (MS-50371) X-Band Diodes

CHARACTERISTIC		B_V	C_{TO}	C_{TVR}	V_R	R_{TH}	P_O	F_o	V_{OP}	I_{OP}	η	Mech. Tun.	HAT	T_J	$Q_{Ext.}$	ΔF_{RMS}	(N/S)AM
TEST CONDITION		1ma	V=O	$V=V_R$													
UNITS		Volts	P_F	P_F	Volts	$^oC/W$	Watts	GHz	Volts	ma	%			^oC		Hz	db
LIMITS	MIN.						3.5	9			20	$\pm$ 250					
	MAX.							11	70	500				200	200	50	115
Serial No.	Diode I. D. Number																
81	41319B-A-1	31.7	23.1	1.88	25	13.1	3.5	9.93	49.5	270	26.2	ok	380x2	154	< 200	.43	-144
82	41319B-A-3	43.9	23.1	1.73	25	13.0	3.5	9.98	55.05	222	28.6	ok	380x2	138	< 200	.68	-144
83	41319B-A-5	47.0	25.9	1.88	25	12.3	3.5	9.94	57.4	230	26.5	ok	380x2	145	< 200	.86	-144
84	41320B-BB-14	40.5	26.4	1.88	25	12.7	3.5	9.84	55.9	246	25.5	ok	380x2	155	< 200	.97	-144
85	41319B-A-8	49.3	25.5	1.87	25	14.9	3.5	9.9	59.2	235	25.2	ok	380x2	180	< 200	.86	-145
86	41319B-A-16	46.2	24.9	1.90	25	15.2	3.5	9.82	58.5	235	25.5	ok	380x2	180	< 200	.86	-142
87	41319B-A-18	47.6	25.1	1.89	25	13.5	3.5	9.8	58.6	250	23.9	ok	380x2	175	< 200	.86	-145
88	41319B-B-3	39.5	23.6	1.90	25	15.9	3.5	9.91	52.1	245	27.4	ok	380x2	172	< 200	.68	-143
89	41319B-B-5	35.0	24.0	1.89	25	12.5	3.5	9.98	50.9	255	27.0	ok	380x2	143	< 200	.31	-144
90	41319B-B-6	45.5	25.8	1.88	25	15.5	3.5	9.83	55.4	265	23.8	ok	380x2	199	< 200	.68	-146
91	41319B-B-8	45.8	26.1	1.88	25	15.6	3.5	9.85	55.5	240	26.3	ok	380x2	178	< 200	.54	-145
92	41319B-B-14	43.9	23.5	1.85	25	14.0	3.5	9.79	56.8	240	25.7	ok	380x2	167	< 200	.77	-144
93	41319B-B-15	38.4	25.9	1.89	25	13.6	3.5	9.79	54.2	255	25.3	ok	380x2	166	< 200	.48	-145
94	41319B-B-16	47.0	25.8	1.85	25	15.3	3.5	9.88	57.5	240	25.4	ok	380x2	182	< 200	.48	-145
95	41319B-B-18	44.7	26.3	1.87	25	15.5	3.5	9.85	56.8	255	24.2	ok	380x2	195	< 200	.48	-145
96	41320B-AA-2	45.2	26.9	1.87	25	13.5	3.5	9.87	57.0	250	24.6	ok	380x2	170	< 200	.86	-142
97	41320B-AA-6	38.3	25.1	1.86	25	14.1	3.5	9.87	54.4	246	26.2	ok	380x2	164	< 200	.86	-143
98	41320B-AA-8	41.8	24.6	1.86	25	14.2	3.5	9.85	57.7	240	25.3	ok	380x2	171	< 200	1.08	-144
99	41320B-AA-10	39.1	25.2	1.87	25	15.0	3.5	9.92	54.1	255	25.4	ok	380x2	179	< 200	1.53	-146
100	41320B-AA-11	40.3	24.6	1.83	25	13.8	3.5	9.96	53.6	253	25.8	ok	380x2	164	< 200	.77	-145

Table 2-2
Data Sheet
(Continued)

CHARACTERISTIC		B_V	C_{TO}	C_{TVR}	V_R	R_{TH}	P_O	F_o	V_{OP}	I_{OP}	η	Mech. Tun.	HAT	T_J	$Q_{Ext.}$	ΔF_{RMS}	(N/S)AM
TEST CONDITION		1ma	V=O	$V=V_R$													
UNITS		Volts	P_F	P_F	Volts	$^oC/W$	Watts	GHz	Volts	ma	%			^oC		Hz	db
LIMITS	MIN.						3.5	9			20	$\pm$ 250					
	MAX.							11	70	500				200	200	50	115
Serial No.	Diode I. D. Number																
101	41320B-AA-12	47.1	26.7	1.85	25	13.9	3.5	9.91	58.9	245	24.3	ok	380x2	177	< 200	1.53	-141
102	41320B-AA-13	41.5	20.5	1.86	25	14.8	3.5	9.95	58.5	235	25.5	ok	380x2	177	< 200	1.53	-147
103	41320B-AA-17	44.2	21.1	1.93	25	14.1	3.5	9.87	58.7	235	25.4	ok	380x2	170	< 200	1.09	-143
104	41320B-AA-19	37.8	25.2	1.91	25	14.3	3.5	10.00	53.8	250	26.0	ok	380x2	177	< 200	.68	-145
105	41320B-AA-20	38.1	25.8	1.90	25	15.5	3.5	9.89	54.0	256	25.2	ok	380x2	187	< 200	1.08	-145

Table 2-3
Data Sheet
SCS-481 Type 2 (MS-50372) Ku-Band Diodes

CHARACTERISTIC		B_V	C_{TO}	C_{TVR}	V_R	R_{TH}	P_o	F_o	V_{OP}	I_{OP}	η	Mech. Tun.	HAT	T_J	$Q_{Ext.}$	ΔF_{RMS}	(N/S)AM
TEST CONDITION		1ma	V=O	$V = V_R$													
UNITS		Volts	P_F	P_F	Volts	$^oC/W$	Watts	GHz	Volts	ma	%			^oC		Hz	db
LIMITS	MIN.						2.5	14			20	± 250					
	MAX.							16	70	500				200	200	50	-115
Serial No.	Diode I. D. Number																
106	41328A-B1-24	23.5	10.5	1.65	15	17.5	2.5	14.31	39.0	290	22.1	ok	190	179	<200	10.1	-136
107	41328A-B2-2	23.8	11.0	1.75	15	18.2	2.5	14.45	39.0	295	21.7	ok	190	189	<200	20.2	-144
108	41328A-B2-4	23.5	10.4	1.68	15	18.3	2.5	14.44	38.7	295	21.9	ok	190	188	<200	18.0	-145
109	41328A-B2-5	23.7	11.0	1.72	15	18.6	2.5	14.31	39.0	297	21.6	ok	190	194	<200	18.0	-147
110	41328A-B2-6	23.9	9.5	1.60	15	18.4	2.5	14.30	39.5	290	21.8	ok	190	190	<200	10.1	-148
111	41328A-B2-14	24.2	8.5	1.75	15	18.7	2.5	14.42	39.3	292	21.8	ok	190	193	<200	16.0	-146
112	41328A-C1-1	24.1	10.7	1.67	15	18.2	2.5	14.07	38.6	300	21.6	ok	190	190	<200	16.0	-147
113	41328A-C1-9	24.2	10.3	1.68	15	18.3	2.5	14.34	37.8	295	22.4	ok	190	183	<200	16.0	-143
114	41328A-C1-21	25.3	8.3	1.67	15	17.9	2.5	14.14	41.6	280	21.5	ok	190	188	<200	16.0	-148
115	41328A-C2-5	24.6	8.3	1.68	15	18.8	2.5	14.38	40.4	285	21.7	ok	190	195	<200	10.1	-159
116	41328A-C2-7	22.9	10.3	1.65	15	18.7	2.5	14.2	38.8	285	22.5	ok	190	186	<200	12.7	-144
117	41328A-C2-8	22.9	10.8	1.66	15	18.5	2.5	14.1	38.2	290	22.6	ok	190	183	<200	16.0	-146
118	41328A-C2-9	22.8	10.4	1.63	15	18.9	2.5	14.2	38.3	290	22.6	ok	190	187	<200	12.7	-145
122	81844M2-2-13	19.9	9.9	1.53	15	17.0	2.5	14.24	35.0	345	20.7	ok	190	188	<200	18.0	-140
123	81844M2-2-15	20.1	9.7	1.55	15	18.1	2.5	14.43	36.1	325	21.2	ok	190	193	<200	14.3	-148
124	81844M2-2-16	22.0	8.8	1.54	15	17.6	2.5	14.60	37.7	305	21.8	ok	190	183	<200	10.1	-152
125	81844M2-2-23	23.0	9.2	1.58	15	18.7	2.5	14.50	36.9	320	21.1	ok	190	200	<200	16.0	-138
126	81844M2-3-8	20.8	10.0	1.56	15	17.0	2.5	14.40	36.8	320	21.0	ok	180	185	<200	16.0	-146
127	81844M2-3-9	19.9	10.0	1.57	15	16.8	2.5	14.38	36.1	320	21.7	ok	190	177	<200	15.0	-146
128	81844M2-3-23	19.0	8.9	1.50	15	17.5	2.5	14.80	35.5	340	20.8	ok	180	191	<200	18.0	-131

Table 2-3
Data Sheet
(Continued)

CHARACTERISTIC		B_V	C_{TO}	C_{TVR}	V_R	R_{TH}	P_o	F_o	V_{OP}	I_{OP}	η	Mech. Tun.	HAT	T_J	$Q_{Ext.}$	ΔF_{RMS}	(N/S)AM
TEST CONDITION		1ma	V=O	$V = V_R$													
UNITS		Volts	P_F	P_F	Volts	$^\circ$C/W	Watts	GHz	Volts	ma	%			$^\circ$C		Hz	db
LIMITS	MIN.						2.5	14			20	± 250					
	MAX.							16	70	500				200	200	50	-115
Serial No.	Diode I.D. Number																
129	81844M2-4-1	21.0	8.3	1.60	15	17.6	2.5	14.58	37.1	310	21.8	ok	190	183	<200	22.6	-142
130	81844M2-5-4	21.5	9.4	1.62	15	18.0	2.5	14.33	37.7	320	20.9	ok	190	170	<200	18.0	-148
119	81844M2-1-2	19.5	8.8	1.50	15	17.6	2.5	14.35	35.7	345	20.3	ok	190	198	<200	18.0	-148
120	81844M2-1-8	22.4	9.5	1.57	15	18.0	2.5	14.60	38.1	305	22.3	ok	200	182	<200	18.0	-143
121	81844M2-1-10	21.8	9.3	1.52	15	16.8	2.5	14.27	36.3	320	21.5	ok	195	178	<200	18.0	-141

To accomplish this, the temperature calibration and pulsing portion of the measurement were separated. A large portion of the total time had been consumed in waiting for the fixture and diodes to heat and to reach equilibrium during the temperature calibration portion during which time the pulsing equipment had also been inaccessible.

A twenty-five position fixture was, therefore, designed and fitted to an oven so that temperature calibration curves could be obtained on twenty-five units simultaneously, separate from the pulsing apparatus. This capacity is adequate for the present requirement and can be readily expanded -- commercial equipment with high throughput can be purchased. Using this system, the diodes are individually tested in turn through a selector switch at room temperature and at a temperature of 125^{o}C.

During the heating and stabilization period, a separate batch of diodes, previously temperature calibrated, can be pulsed. To increase the rate for this portion of the measurement, a test instrument was purchased from Sage Enterprises. This instrument measures devices and provides a digital readout of the result in nine seconds. The throughput is limited by the desired accuracy, which sometimes requires that the measurement cycle be repeated (i.e., when the diodes are not sufficiently uniform in characteristics), and by loading, unloading and data recording.

Considering all aspects of the thermal resistance measurement, devices are now measured at the rate of 75-100 units per eight-hour shift by a single operator. For simpler devices such as flat-profile IMPATTs, the temperature calibration of breakdown voltage is performed on a sample basis and much higher rates are realized.

The accuracy and repeatability of the measurement has been analyzed. A discussion of these aspects of the measurement

follows. All of the discussion is referenced to the Sage instrument shown in Figure 2-5. In the use of this instrument, the temperature coefficient of avalanche breakdown voltage is normalized to the room temperature breakdown voltage and is referred to as the Beta Factor (β).

$$\beta = \frac{V_{B2}-V_{B1}}{(T2-T1)\ (V_{B1})}$$

where: V_{B2} = Breakdown Voltage at T2 (ex. 125°C)

V_{B1} = Breakdown Voltage at T1 (ex. 25°C)

2.2.1 Temperature Coefficient of Avalanche Breakdown

Most methods for measuring the thermal impedance of IMPATT diodes use the device as its own thermometer for measuring its junction temperature. This is accomplished by heating the device in an oven and measuring the avalanche breakdown voltage (V_B) at a small sense current. The slope of the "breakdown voltage versus temperature" curve, normalized with respect to room temperature voltage, is the β coefficient. Potential sources of error in measuring and applying β have been analyzed.

A potential source of error in measuring the breakdown voltage is the voltage drop across contact resistances. To establish whether this was significant, the measurement was simulated using an empty diode package internally short circuited. The results indicate a residual resistance of 0.5 ohms in the system which corresponds to a voltage drop of 1 mV or less in a current range of 1-2 mA. This is insignificant when compared to the resolution in measuring the breakdown voltage, which for the present equipment can be measured with an accuracy of ±50 mV including the error due to a 5% uncertainty in the sense current.

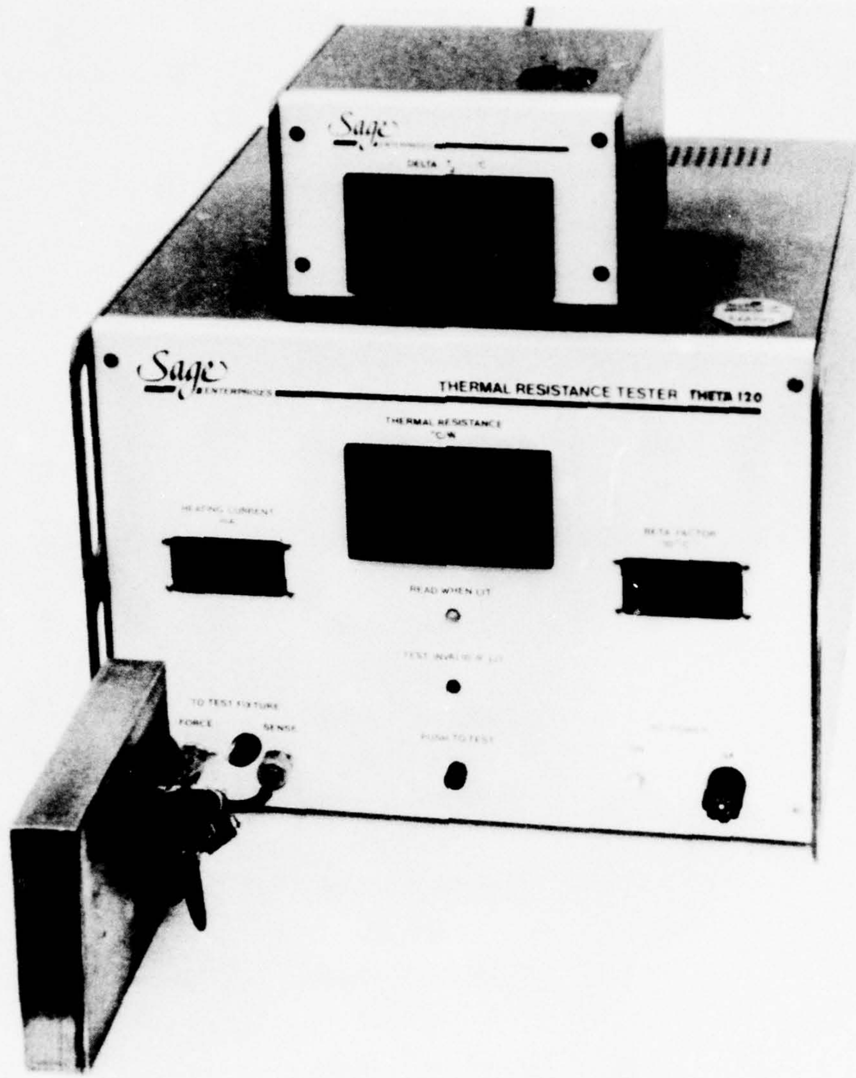

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Figure 2-5 Photograph of Sage Instrument

Temperature is directly monitored in ^{o}C by a digital temperature indicator with a $0.1^{o}C$ resolution and $\pm 0.5^{o}C$ accuracy. Calibration was checked at the ice point and water boiling point. An offset of $0.1^{o}C$ was found. This offset does not really affect β measurements since it is eliminated in the subtraction, and β is a function of ΔT instead of just T. Hence, there is a $\pm 0.6^{o}C$ uncertainty in the indicated temperature. The diodes are mounted in an aluminum block having a thermocouple attached. The temperature uniformity of the block was checked and found to be better than the accuracy of the measurement.

The contribution to heating by the power dissipated in the diode at low currents was considered. For diodes of interest having the following typical characteristics:

V_B ($25^{o}C$) = 40 Volts

V_B ($125^{o}C$) = 47 Volts

R_{th} = $23^{o}C/W$

the junction temperature increase at bias currents of 1 mA and 2 mA is

	I_S = 1 mA		I_S = 2 mA	
	$25^{o}C$	$125^{o}C$	$25^{o}C$	$125^{o}C$
Contribution to Heating (^{o}C)	0.92	1.08	1.84	2.16

If the only effect of I_S is as shown above, the error in β will be insignificant due, once again, to the ΔT rather than T dependence of β.

A curve of V_B versus T for a typical diode is shown in Figure 2-6. The curve is nonlinear over the entire temperature

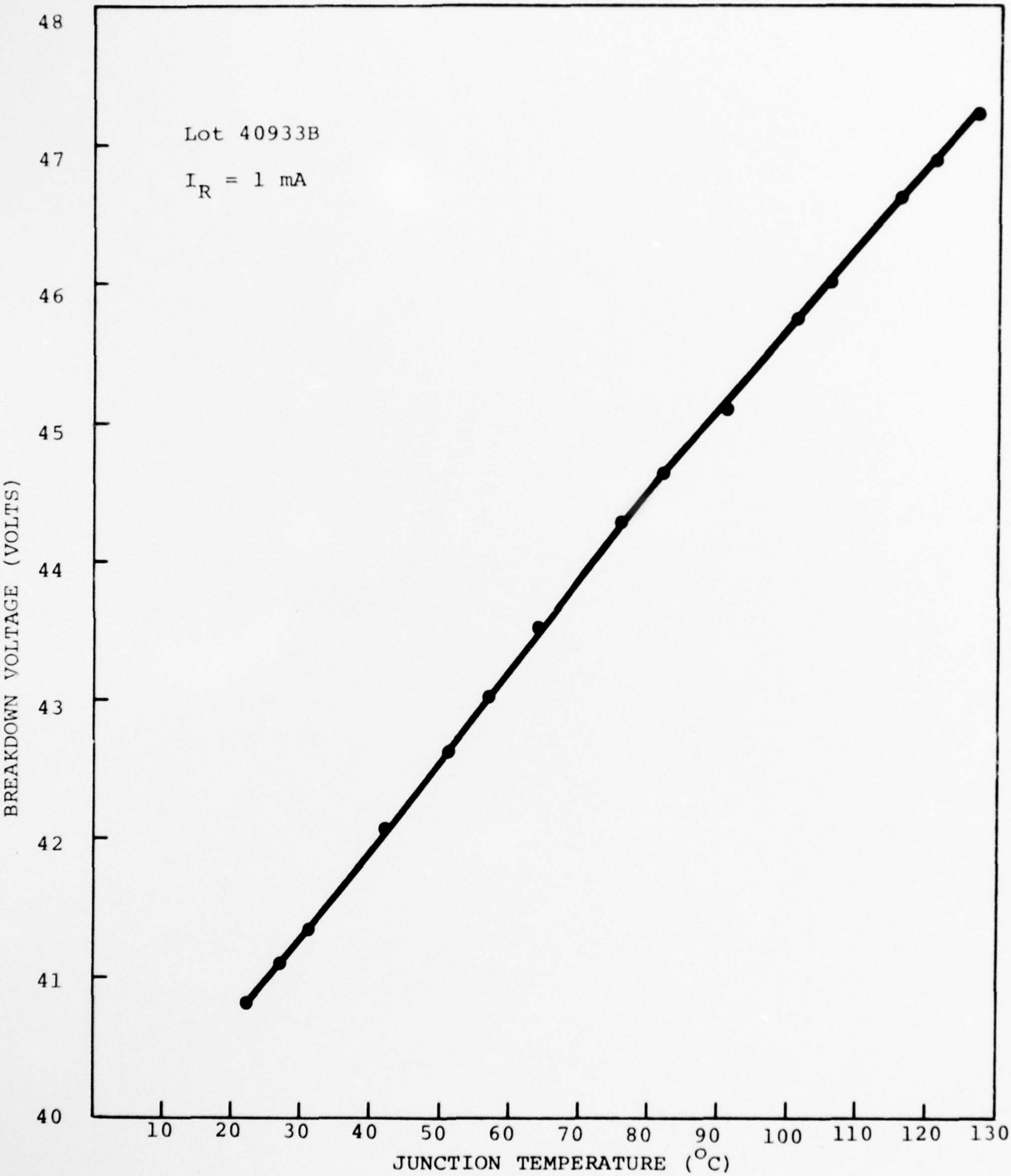


Figure 2-6 Curve of V_B versus T for Typical Diode

range. A linear approximation does not introduce a very large error, but this error can be entirely eliminated even in a production environment by proper application of technique. During measurement of β, the same temperature end points should be consistently used. We have selected $25^{o}C$ and $125^{o}C$ as these points. This corresponds to a ΔT of $100^{o}C$. During the pulse measurement on the Sage, the diode is always heated with sufficient power to achieve the same $T = 100^{o}C$. With this approach, the shape of the V_B versus T curve between the two points does not affect the accuracy of the measurement.

The repeatability of the V_B versus T curves was evaluated by testing points on the curve on several different days. This data is given in Figure 2-7 as identified in the legend and shows that the repeatability is quite good.

Other observations resulting from the investigation indicate that the nominal value of β is lot dependent, and the standard deviation within a lot varies from 1.4% to 3.4% for the lots tested. The value and distribution of β are also current dependent. The mean β per lot is lower and the distribution tighter at $I_S = 2$ mA than at 1 mA. These observations do not affect the accuracy of the measurement as described, but rather determine the accuracy obtainable from performing a sample test of β if this technique were adopted.

A detailed error analysis was performed in order to understand and place in perspective the degree to which the error of each measurement cumulatively affects β.

$$\beta = \frac{\Delta V_B}{\Delta T} \frac{1}{V_{B_i}} \equiv S \frac{1}{V_{B_i}}$$

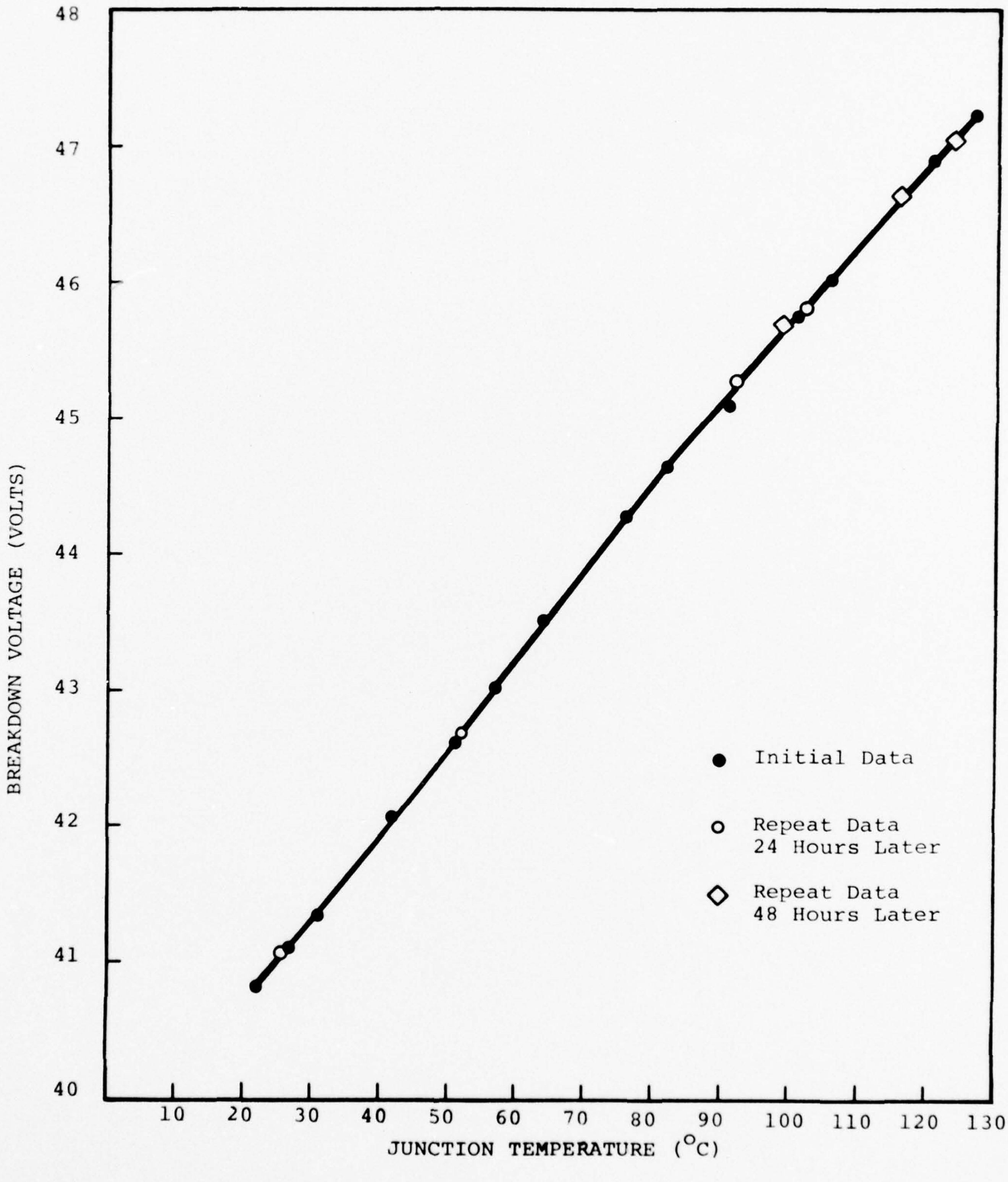


Figure 2-7 Repeatability of V_B versus T Curve

1) $$\frac{\Delta S}{S} = \pm\left(\frac{\Delta T}{(\Delta T \mp 2t)} \quad \frac{(\Delta V \pm 2v)}{\Delta V} \quad -1\right)$$

where: v = the error in V_B.

t = the error in T.

If for example,

$\Delta V_B = 6V$

$\Delta T = 100^{o}C$

$v = \pm 0.050V$

$t = \pm 0.6^{o}C$

$\frac{\Delta S}{S} = \pm 2.9\%$

Hence, the uncertainty in the calculated slope is $\pm 1.7 \times 10^{-3} V/^{o}C$.

2) $$\frac{\Delta \beta}{\beta} = \pm\left(\frac{S \pm s}{S} \quad \frac{V_{B_i}}{V_{B_i} \mp v} \quad -1\right)$$

where: s = the error in S.

For example,

$S = 0.058V/^{o}C$

$s = 0.0017V/^{o}C$

$V_B = 40.0\ V$

$v = 0.05V$

$\frac{\Delta \beta}{\beta} = \pm 3.1\%$

The example above indicates a 3.1% uncertainty in β due to various

measurement errors only. Since β is a normalized coefficient with respect to V_{B_i}, which is a function of T_i, a new source of error exists, unless T_i at β measurement is the same as the R_{th} measurement. In other words, the diode heat sink temperatures should be the same when determining V_{B_i} and R_{th}. A simple calculation indicates the relative significance of a worst case $\Delta T_i = \pm 5^{\circ}C$.

$S = 0.058\ V/^{\circ}C$

$s = \pm 0.0034\ V/^{\circ}C$

$V_B = 40.0\ V$

$v = \pm 0.05 \pm .29 = 0.34\ V$

Meas. Error T_i Error

$\frac{\Delta\beta}{\beta} = \pm 3.8\%$

In summary, @ $T = 100^{\circ}C$, a 0.6% error in T and 0.13% error in V_{B_i} cause a 3.1% error in β. An uncertainty of 0.29 Volts in V_{B_i} due to a worst case $5^{\circ}C$ difference in heat sink temperatures (R_{th} versus β heat sinks) adds another .7% to the error in β. The preceding actual laboratory measurements indicate an uncertainty in β of about 3%.

2.3 Thermal Resistance Tester

Early in the program, the unit shown in Figure 2-5 was purchased from Sage Enterprises to replace the test set in use at the time (Figure 2-8). The motivation improved speed, accuracy, and simplicity of operation.

Upon delivery, it was found that the instrument, indeed, promised greatly improved production rates because of the rapidity of measurement and computation relative to the existing equipment. Correlation with the existing method was poor, however, which led to a rather comprehensive evaluation exercise. The following conclusions

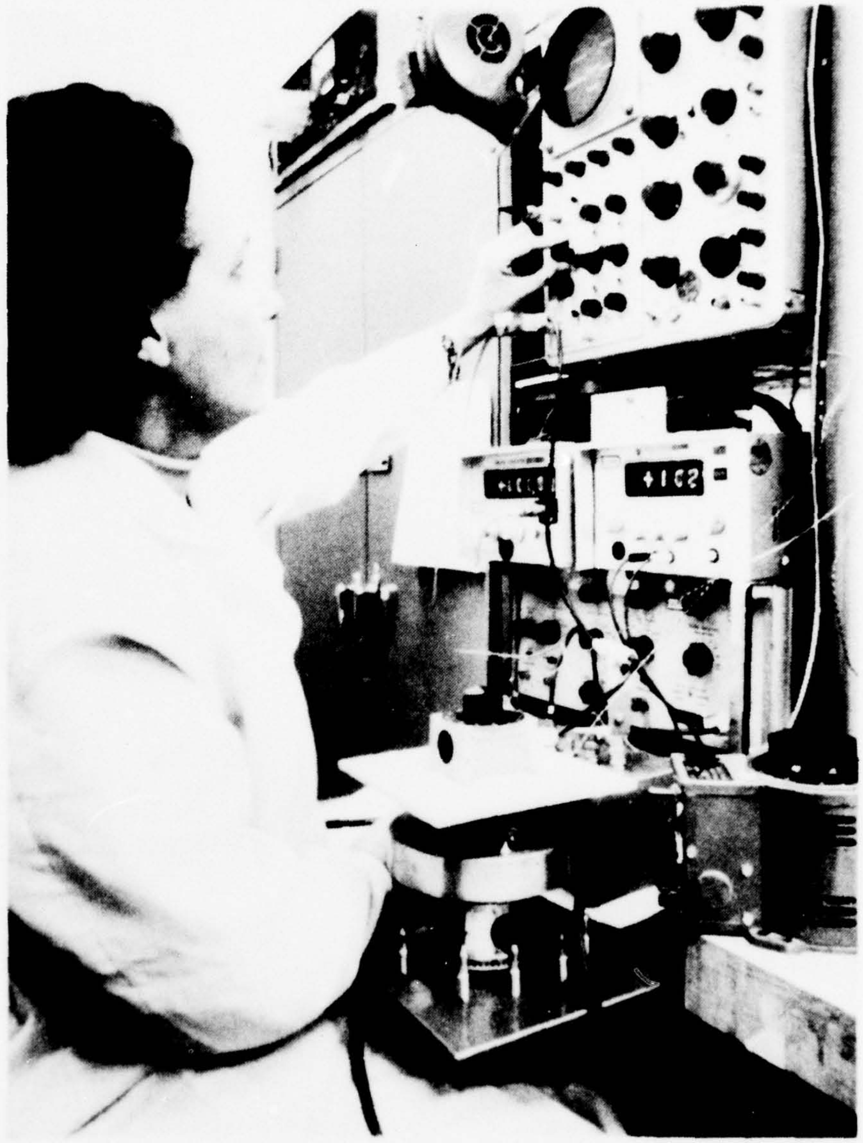


Figure 2-8 Thermal Resistance Test Set

resulted from the evaluation:

1) Repeatability of measurement was excellent over a short time period (days).

2) There was an occasional shift in the measurements which were again very repeatable at the new level over a short time period (days).

3) Thermal resistance varied greatly as the input power was changed leading to uncertainty in the true value which made the correlation problem appear worse.

The instrument was returned to the vendor with all of the test data. The shift in measurement level was explained as being due to a defective integrated circuit component and was quickly corrected.
sought. The variation in thermal resistance required design modifications, necessitated in part by the properties of the devices being tested. Sharp pulses used to switch the diode rapidly apparently caused the diode to oscillate which led to inaccuracies in measured currents and voltages used in the computation. This problem was solved by adding lossy material to the diode terminals to damp the oscillations. During the evaluation, it had also been concluded that knowledge of the junction temperature during test would be a desirable feature. This feature was added as the accessory digital meter shown in the figure.

The "Theta 120" was subjected to a second evaluation by the vendor and also by Raytheon. Based upon these tests, the instrument was accepted and is being phased into the production line.

Standard diodes have been designated and are measured each time the instrument is used. Repeatability of measurement is excellent and is about 0.5% over a two-month period. Correlation with the prior method continued to be somewhat erratic for a while. Initially, the approach had been to apply a factor to the Sage via an

artificial value for β to force agreement between the two methods. Using this technique, highly reproducible thermal resistance data was obtained for all devices, and this data agreed with the method which had been in use up to this time.

Meanwhile, the potential source of errors in the two techniques was examined, and data was obtained from other sources. It was concluded as a result of the program that the Sage instrument gave more accurate results than the prior method. The differences are explained by how fast the junction temperature is sensed following interruption of the heating pulse. The short thermal time constant of these devices imposes the requirement. Correction of the standard method for cooling which occurred during switching gave results in close agreement with the Sage unit.

2.4 Noise Measurement of IMPATT Diodes

The original AM and FM noise measurements, on the engineering sample Read diodes, were performed on an elaborate, general purpose setup at Raytheon's Research Division. This particular measurement system was conceived mainly for research and development needs, hence became quite unsuitable for production testing. Disregarding setup time, one could measure at the rate of two to four diodes a day. The main cause for the low throughput is the need for constant recalibration of AM and FM sensitivity. This problem is compounded when measuring FM noise by small drifts in the carrier frequency. After obtaining the point-by-point data, it must be submitted to calculations to obtain the results and then manually plotted.

During the course of this program, a computer program was developed to accept the raw data, perform the calculations, and plot the results. Samples of the resultant curves were included in prior reports. This was mainly for convenience of the operator and gave more presentable data, but resulted in only 10% rate improvements.

Several alternatives for faster measurement systems were considered. A circuit design was completed for a "go-no-go" system which appeared quite attractive. An excellent alternative was found, however, in a powerful carrier noise analyzer, Model CNA-20, manufactured by the Electronics Equipment Group of Raytheon's Microwave and Power Tube Division. The unit was originally designed for measuring low noise tubes. This unit uses a microwave discriminator and direct detection techniques, thus eliminating the complex operations and adjustments associated with heterodyne systems. Self-calibration is accomplished directly at the microwave frequency. Achievable rates exceed ten times that of the former method.

Such a carrier noise analyzer for Ku-band has been acquired and evaluated. The unit is shown in Figure 2-9. The unit, in conjunction with a low frequency spectrum analyzer and an X-Y recorder, yields a hard-copy plot of noise as a function of frequency from carrier. A typical plot is given in Figure 2-10.

The measurement of semiconductor device noise is quite often limited by the power supply used in biasing the device under test. An evaluation of such limitations in the case of Ku-band Read diodes was conducted. The power supply "pushing" figure is defined as the ration of the deviation frequency to the "pushing" signal voltage (FM). Then the power supply noise level was plotted. At 10 KHz, the plot indicates a noise level of about -107 dBV which corresponds to an equivalent frequency ($\Delta f \approx$ 200 Hz/100 Hz-BW). All measured devices indicate an FM noise level of about the same magnitude; hence, it is believed that the actual FM noise level of the diodes is below this level. In the case of AM noise, both the power supply level and diode noise level are below the limiting sensitivity of the noise analyzer.

Figure 2-9 Photograph of Carrier Noise Analyzer (Model CNA-20)

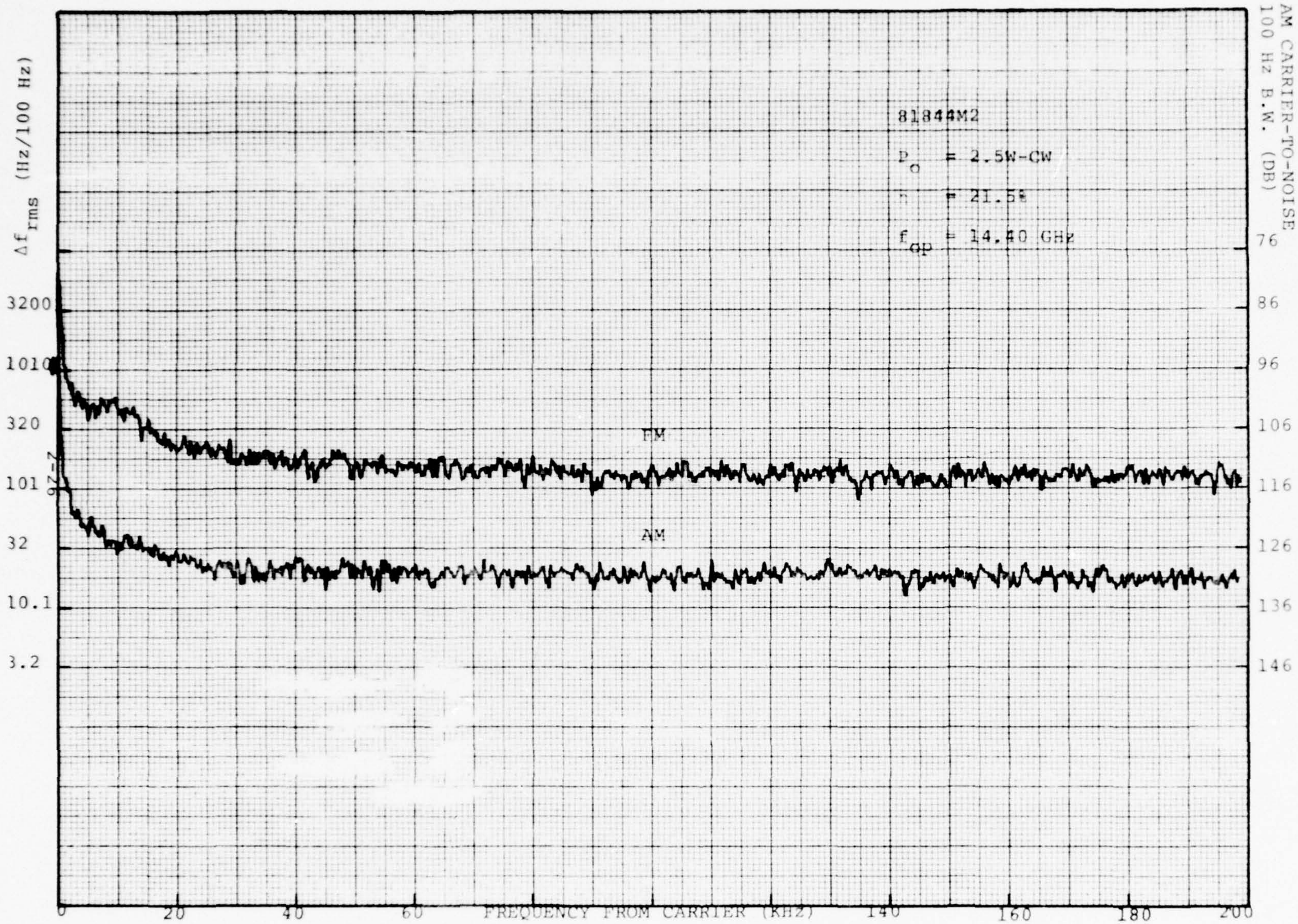


Figure 2-10 Plot of Noise as a Function of Frequency from Carrier

3.0 DIODE OPERATING LIFE TESTS

3.1 Summary of Requirements

Operating life test requirements of this program specify that diodes periodically be subjected to 1000-hour life tests while operating as oscillators. The tests are to be initiated at the end of the first quarter and repeated quarterly for a total of seven (7) tests. The sample size for each test is five (5) diodes of each type randomly selected from a corresponding wafer. In addition, nine (9) diodes of each type are to be life tested for 1000 hours as a part of the Group B Quality Conformance Inspection at the time of confirmatory sample testing and again at the time of pilot run sample testing.

The testing is to be conducted at an ambient temperature of 25°C with the test cavity temperature held below 75°C and the diode junction temperature not exceeding 200°C. To identify failures, the power output must be monitored with failures defined by a 25% decrease in the power output of a diode relative to its initial value. The Group B life testing will be performed with the diode operating within its rated power output, frequency, efficiency, and junction temperature specifications. The quarterly tests will be conducted in such a way as to demonstrate progress toward successfully meeting these test requirements.

Two operating life test stations, one for X-band diodes and one for Ku-band diodes, were designed and constructed to meet the operating life test requirements described. A description of the equipment was presented in the first quarterly report.

3.2 Results of Test

During the present period, the fifth operational life test was completed for the Ku-band diodes only. Testing of the

X-band diodes was delayed so that life testing of the X-band confirmatory samples could be conducted.

Four diodes completed the test (1079 hours) without degradation of output power. The fifth diode failed at 638 hours. There was no change in operating characteristics of the failed diode prior to failure. The operating voltage was 35.4 ±0.1 Volts during the entire period up to the point of failure. The current was also stable at 350 milliamperes. It is felt that failures of this type are due to circuit problems rather than defects in the diode. All diodes are subjected to a dc burn-in subsequent to final encapsulation and prior to rf testing. Diodes having manufacturing defects which would tend to make them fail in an abrupt manner are usually screened out during the burn-in. The surviving diodes generally fail in a different way. Failure is preceded by a gradual increase in operating voltage if the bias is supplied from a constant current source. A possible cause of the present failure is detuning of the cavity. The cavity used for life testing includes a sliding short which has been found to be somewhat erratic. Jarring of the life test bench could cause detuning if the short was critically positioned during the tuning cycle.

After removal from the life test rack, the four surviving diodes were retested. The data is given in Table 3-1. It may be seen that the original data was quite accurately reproduced, verifying that the diodes did not degrade during the life test. The diodes were operated at full rated power and met all of the specifications.

During the present test, a fuze on the program blew at 212 hours and data was not recorded for the following twelve hours. The equipment operated normally after the fuze was replaced. At 653 hours, power was interrupted in the building for maintenance work. The test was restarted without incident after the power was restored.

Table 3-1

Operating Life Test Data - Ku-Band Diodes

	Diode No.	Rack Position	Resistance (°C/W)	Junction Temp. (°C)	Operating Voltage (Volts)	Operating Current (mA)	Power Out (Watts)	Freq. (GHz)	Dissipated Power (Watts)
Initial	81844M2D-4	1	18.0	193.7	37.1	320	2.5	14.33	9.4
Final					37.5	320	2.5	14.32	
Initial	81844M2B-3	2	17.2	194.5	35.3	350	2.5	14.45	9.9
Final					----	---	---	-----	
Initial	81844M2A-7	3	17.1	184.8	35.9	330	2.5	14.71	9.3
Final					35.9	335	2.5	14.70	
Initial	81844M2A-13	4	17.0	188.0	37.2	325	2.5	13.7	9.6
Final					36.8	330	2.5	14.1	
Initial	81561MC-9	5	18.1	191.7	36.6	320	2.5	14.28	9.2
Final					37.3	325	2.5	14.28	

Specification:
P_o = 2.5 W minimum
f_o = 14-16 GHz
η = 20% minimum
T_j = 200°C maximum

3.3 Status of Operating Life Test Program

The following is a summary of the results obtained to date during the operating life test program:

Test Number	X-Band Qty. Tested	X-Band Qty. Failed	Ku-Band Qty. Tested	Ku-Band Qty. Failed
1	5	1	5	1
2	5	1	5	5*
3	5	1	5	0
4	5	0	5	0
5	0	0	5	1

* System malfunction caused catastrophic failure of all devices during test.

4.0 CONCLUSIONS

During the period, we have installed two new equipments which will enable production of Read diodes at the rate of 1000/month.

The confirmatory samples have been assembled and are undergoing Group B testing.

5.0 PROGRAM FOR NEXT INTERVAL

During the next interval, we will complete the Group B testing of the confirmatory samples. The program will enter the pilot production phase. Documentation is being prepared for this phase, including methods for recording rates and yields.

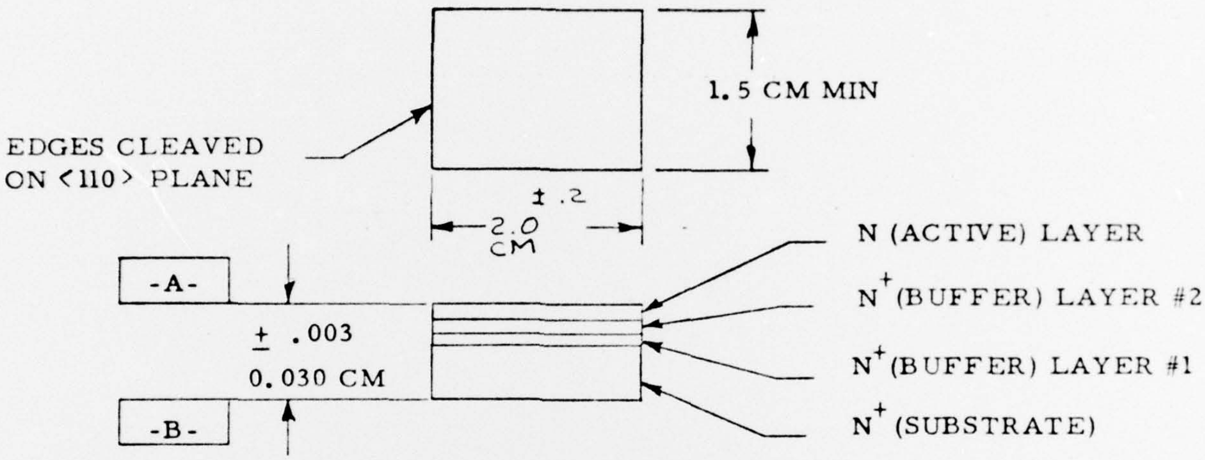
6.0 IDENTIFICATION OF PERSONNEL

Michael Benedek Engineer - Production Processes	202 Hours
Robert Bierig Manager - Semiconductor Research Laboratory and GaAs Material Production	7 Hours
Henri Chalifour Manager - Diode Production	100 Hours
Dr. S. F. Paik Manager - Solid State Engineering	10 Hours
Basil Vafiades Programs Manager - MMTE Program Manager	65 Hours
Production Technicians	222 Hours
Research Technicians	25 Hours
Drafting	3 Hours
Machine Shop	46 Hours

APPENDIX A

SPECIFICATION
GaAs EPITAXIAL WAFER READ PROFILE

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED
		1	REVISED EXTENSIVE CHGS. SEE OBSOLETE FILE FOR PREVIOUS REV	9-11-75	
		2	PARAMETER 4.6 $1.0 \times 10^{16} \pm 10\%$ WAS $7.5 \times 10^{15} \pm 10\%$	12/15/75	
		3	REV. EXTENSIVELY PER ENG. MARK UP	12-17-76	
		4	REV. PER ENG. MARKUP	3-15-77	



NOTES:

1. Usable area - 3.0 cm^2/min.

2. Fifty (50) percent of the wafers grown shall have eighty (80) percent, (minimum area 3.0 cm^2/wafer) of usable material. The term usable defines material which meets specifications for dislocation density, doping profile and is capable of producing diodes meeting specification SCS-481, 23 September 1974.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES	CONTR NO.		RAYTHEON	RAYTHEON COMPANY LEXINGTON, MASS. 02173
TOLERANCES: ANGLES ±	DR. R. S[illegible]	4-5-[illegible]		
FRACTIONS ±	CHK		DRAWING TITLE	
3 PLACE DECIMALS ±	APPD [illegible]	12-20-76		
2 PLACE DECIMALS ±	[illegible]	12-22-76	GaAs EPITAXIAL WAFER READ PROFILE	
1 PLACE DECIMALS ±				
MATERIAL:	APPROVED		SIZE A	CODE IDENT NO. 49956 — DRAWING NO. 892049
	BY DIRECTION OF		SCALE ——	Rev. 4 — SHEET 1 OF 4

10—0700 (5/68) VELLUM
10—0701 (5/68) GRID VELLUM
10—0702 (5/68) FILM

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SPECIFICATIONS

1. SUBSTRATE

1.1 Resistivity: 2×10^{-3} ohm-cm max.

1.2 Carrier Concentration: $1 - 4 \times 10^{18}/cm^3$

1.3 Dopant: N-Type

1.4 Etch Pit Density: $10^4/cm^2$ max.

1.5 Orientation: $2 \pm 1/2^o$ off $\langle 100 \rangle$ towards $\langle 110 \rangle$ plane.

2. BUFFER LAYER #1

2.1 Resistivity: 2×10^{-3} ohm-cm max.

2.2 Carrier Concentration: $1 - 4 \times 10^{18}/cm^3$

2.3 Dislocation Density: $1000/cm^2$

2.4 Dopant: Silicon

2.5 Thickness: 4.0 - 10.0 μm

3. BUFFER LAYER #2

3.1 Carrier Concentration: $1 - 4 \times 10^{17}/cm^3$

3.2 Dislocation Density: $1000/cm^2$

3.3 Dopant: Silicon

3.4 Thickness: 1 μm $\pm$ 0.5 μm

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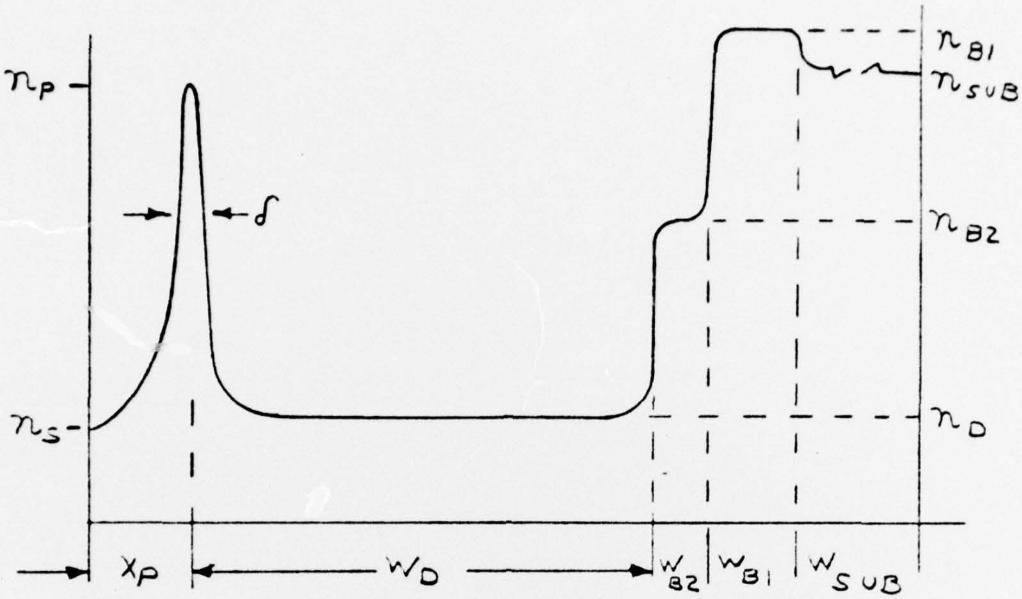
4. <u>ACTIVE LAYER:</u> Per Table I



TABLE

	PARAMETER	SYMBOL	PART NUMBER -1	PART NUMBER -2	UNITS
4.1	Nominal Operation Freq. Range		X-Band	Ku-Band	
4.2a	Carrier Concentration at X_o	N_o	1.0×10^{17}		cm^{-3}
4.2b	Zero Bias Depletion wd.	X_o	0.20		m
4.3	Peak Depth	X_P	$0.24 \pm .02$		μm
4.4	· Total charge in spike per unit area	Q	$2.4 \times 10^{12} \pm 0.4$		$coul/cm^2$
4.5	Spike width max. at half height	Max.	0.06 max.		μm
4.6	Drift Space Doping	n_D	$5 \times 10^{15} \pm 10\%$	$1.0 \times 10^{16} \pm 10\%$	cm^{-3}
4.7	Active Layer Thickness	W_D	5.0 ± 0.5	4.0 ± 0.5	μm
4.8	Spike Depletion Voltage	V*	8.3 ± 1.0		Volts

SIZE	CODE IDENT NO.	DRAWING NO.
A	49956	892049
SCALE	REV	SHEET 3 of 4

5. <u>SURFACE "A" FINISH</u>

5.1 Surface "A" to be mirror-like with no hazy frosty appearance.

5.2 Surface "A" of wafer (exclusive of 1.5mm wide edge) to have a maximum of four gross defects (pits or mounts). Each defect shall be less than 1/2 mm in diameter and shall have a maximum height of 1 μm.

6. <u>DATA REQUIREMENTS (EACH WAFER)</u>

6.1 Identify substrate vendor and supply vendor crystal number.

6.2 Supply vendor data on 1.1, 1.2, 1.4 and best estimates on 2.1, 2.2, 2.3, 2.5, 3.1, 3.2, 3.4, 4.2 - 4.8.

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